SCREENING EFFECT OF PLASMA FLOW ON RESONANT MAGNETIC PERTURBATIONS IN EXTRAP T2R

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INTRODUCTION

Resonant magnetic perturbations (RMPs) are a promising tool for mitigation and/or suppression of edge localized modes (ELMs) and for the optimization of neoclassical tearing mode stabilization. However, the RMP penetration into the plasma might be screened by the plasma flow, limiting the capabilities of the technique.

This work is a study of the RMP screening due to the plasma flow in EXTRAP T2R. The machine is equipped with a feedback system able to suppress all error fields and to produce one or more external perturbations in a controlled fashion [1,2]. In the first part of the work experimental results are shown. In the second part, experimental results are compared with numerical simulations performed with the NIMROD code [3] adapted to the EXTRAP T2R geometry and equilibrium.

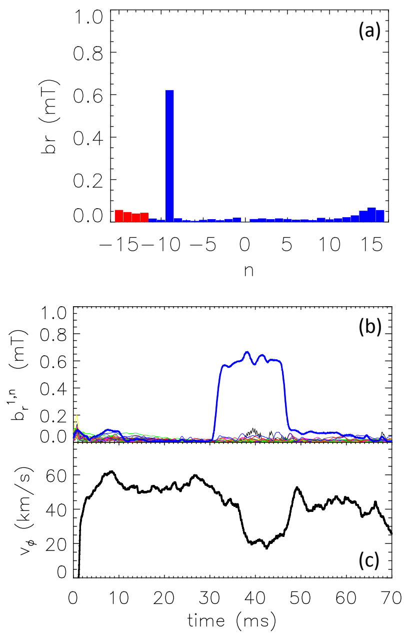

Figure 1. Frame (a): radial magnetic field spectrum at the plasma edge during the application of a non-RMP. Frame (b) time evolution of the magnetic perturbations. The blue line corresponds to the non-RMP harmonic (1,-9). Frame (c): time evolution of the TM velocity for the innermost resonant harmonic.

EXPERIMENTAL RESULTS

To quantify the RMP screening, the following strategy is adopted: (i) the effect of the RMP on the plasma is quantified by monitoring the dynamics of its corresponding TM. Previous works [4,5] show that a static RMP affects the corresponding TM island by amplifying and suppressing its amplitude and producing acceleration-deceleration periods to its velocity, depending on the relative phase between the RMP and TM. (ii) Plasma shots are carried out with identical RMPs together with a non-resonant perturbation. This non-resonant field reduces the plasma flow via the neo-classical viscosity (NTV) torque, as described in [6,7] and it is used to modify in a relatively controlled way the plasma velocity.

An example of the non-RMP effect on the plasma velocity is shown in figure 1, where an external perturbation with amplitude 0.6mT is applied between 30ms and 45ms. In this example the harmonic applied has poloidal and toroidal mode number (m,n)=(1,-9), which in EXTRAP T2R corresponds to a non-resonant harmonic, the first resonant being n=-12. Figure 1(c) shows the time evolution of the (1,-12) TM velocity, which, assuming co-rotation between TMs and plasma, can be considered as representative of the flow in the core.

The plasma velocity is modified from shot to shot by changing the non-RMP amplitude. This is shown in figure 2(a), where the results from five shots are summarized. Each shot is characterized by a different non-RMP amplitude, ranging from ≈0.45mT to ≈0.85mT. Both the (1,-12) TM velocity and the line integrated OV velocity (when available) are shown. By increasing the non-RMP amplitude, the velocity is reduced from ≈40km/s at the lowest non-RMP to ≈15km/s at $b_r^{1,-9}$≈0.8mT. The unperturbed velocity, i.e. with non-RMP amplitude 0mT, is approximately 45-50km/s. Similar trends are obtained for TM and OV velocities. Note that the non-RMP affects only the plasma velocity and that no significant changes are observed in other plasma parameters such as impurity content, current and equilibrium, figures 2(b)-2(d).

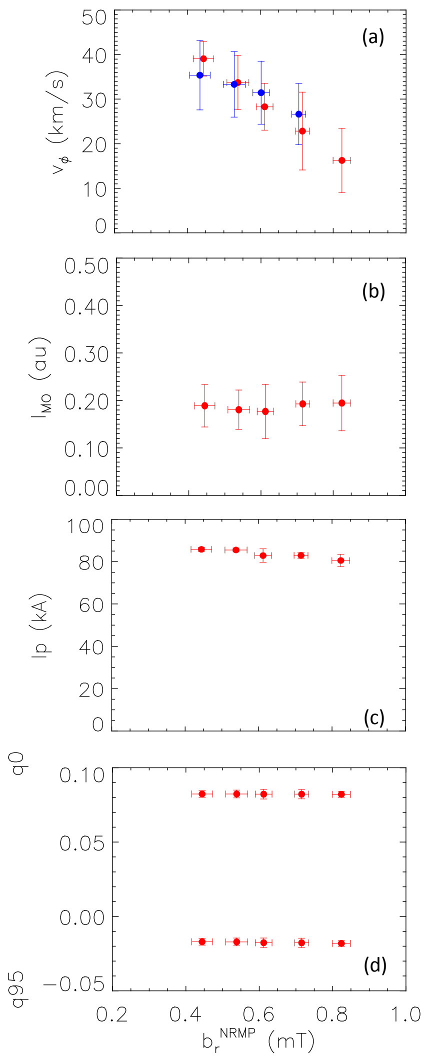

Figure 2. Dependence of several plasma parameters on the non-RMP amplitude. Frame (a) shows the TM velocity (red dots) and the line integrated OV velocity. Frame (b) the impurity content monitored as the intensity of the Molybdenum line MoI., frame (c) the plasma current and frame (d) the equilibrium, where q0 is the safety factor on-axis and q95 the safety factor at r/a=0.95.

A set of shots similar to those described in figure 2 are repeated with an additional RMP of harmonic (1,-12) and amplitude 0.6mT. In figure 3(a) the results are summarized by showing the correlation of the TM amplitude versus the plasma velocity. In the figure, each point corresponds to the time average during an interval in which the perturbations are applied and in which the velocity has reached a steady value. The empty circles show the reference case, i.e. the result with the non-RMP only. By changing the plasma flow, the TM amplitude is not significantly affected. The full dots represent the case when the RMP is also present. At low plasma velocity, the RMP produces a clear effect on the TM amplitude. At $v_\phi \approx 5$km/s the TM is amplified to ≈0.5mT. In contrast, despite the fact that the RMP amplitude is constant, at high plasma velocity the RMP effect on the time averaged TM amplitude is negligible. This might be considered as an effect of the flow screening on the RMP penetration.

To understand in more detail the behaviour of the TM, figures 3(b) and 3(c) show the time evolution of the TM amplitude and TM phase in 0.1ms time interval. Three cases are shown:

(a) no RMP and velocity $v_\phi \approx 35$-40km/s (black thin line).

(b) 0.6mT RMP and velocity $v_\phi \approx 35$-40km/s (red thin line).

(c) 0.6mT RMP and velocity $v_\phi \approx 10$-15km/s (blue thick line).

With no RMP, the TM amplitude does not change significantly in time and the TM velocity is constant. When the RMP is applied, TM amplitude is characterized by oscillations, with phases of amplification and suppression. At low plasma velocity, these oscillations have lower frequency but higher amplitude. This is due to the fact that the amplification-suppression phases are related to the relative phase between the RMP and the TM. Therefore, in the low velocity case, the TM remains in the amplification phase for a time interval longer than in the high velocity case and higher amplitude is reached.

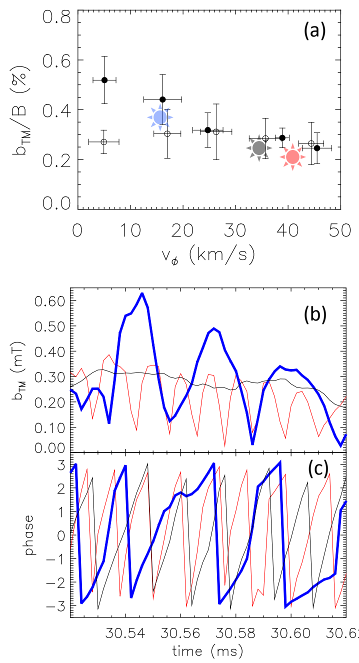

Figure 3. Frame (a): Dependence of the (1,-12) time averaged TM amplitude on the plasma velocity without (open circles) and with (filled circles) a 0.6mT (1,-12) RMP. Time evolution of TM amplitude and phase in a 0.1ms time interval without RMP (black line), with RMP and high velocity (red line), with RMP and low velocity (blue line). The stars in frame (a) highlight the position in the amplitude-velocity diagram of the three cases shown in frame (b).

SIMULATION RESULTS

Nonlinear MHD simulations in the EXTRAP T2R geometry are performed. Typical EXTRAP T2R equilibrium is used. The simulations are performed with the extended MHD code NIMROD [3,8] using an initial velocity profile compatible with the experimental measurements. Plasma viscosity within experimental estimations is used. An RMP field with amplitude 0.6mT and harmonic (1,-12) at the plasma edge is applied from 0.1ms. Figure 4(a) shows that the magnetic energy for the (1,-12) TM increases soon after the RMP is applied while the velocity is reduced to a lower steady value, figure 4(b). Clear amplitude oscillation appears during the phase with steady velocity, in qualitative agreement with experimental results. After 0.4-0.5ms wall locking occurs.

The effect of high and low rotation is shown in figure 5. In the high rotation case (initial toroidal velocity 50km/s), there is a brief period where the plasma remains in the unreconnected (fully screened) state. For higher viscosity, the period during which the RMP is fully screened is further extended. Once the plasma is slowed sufficiently, it enters the reconnected state and the island forms and briefly rotates before locking. In the low rotation case (initial toroidal velocity 25km/s), the plasma enters the reconnected state immediately when the boundary field reaches full amplitude. The nonlinear state that exists before the island locks also shows fewer oscillations.

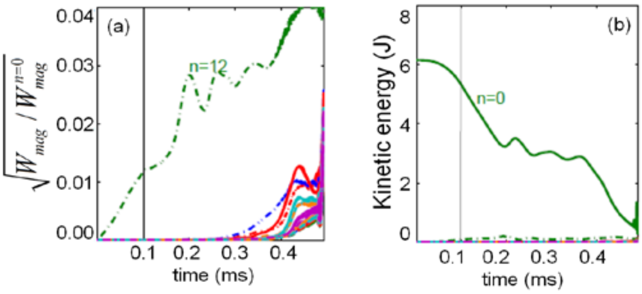

Figure 4. Simulated time evolution of TM amplitudes (a) and kinetic energy (b). A RMP field with amplitude 0.6mT and harmonic (1,-12) is applied at 0.1ms.

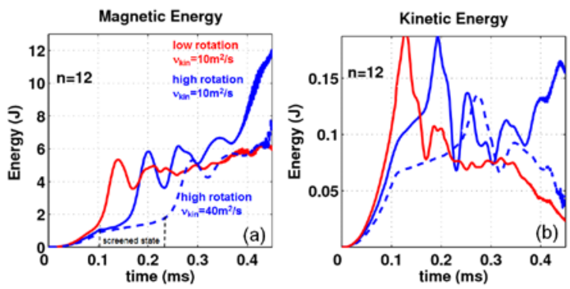

Figure 5. Magnetic (a) and kinetic (b) energy for the (1,-12) TM with RMP. The low and high rotation cases are shown in red and blue respectively, and higher viscosity with dashed curve.

CONCLUSIONS

This work is a study of the RMP effect on the TM dynamics with high and low plasma rotation, which investigates possible plasma flow screening of the RMP penetration. Experimental results show that with high rotation the RMP has a smaller influence on the TM amplitude than at low rotation. Preliminary numerical simulation of EXTRAP T2R plasmas show that in the high rotation case the plasma remains in the (fully) screened state until the velocity is sufficiently slowed, while in the lower rotation case the reconnection occurs soon after the RMP application.

References

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